# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2010 SCORING GUIDELINES

## General Notes

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for the solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong — for example, a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics Exams equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics Course Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of $10 \text{ m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

## Question 1

**15 points total** | **Distribution of points**

(a) 3 points

For indicating that the potential at point $B$ ranks 1 (has the highest potential) — 1 point
For indicating that the potentials at points $A$ and $C$ are equal and rank 2 — 1 point
For a correct justification — 1 point
Example: Compared to points $A$ and $C$, point $B$ is closer to most, and possibly all, points along the charge distribution. Since potential varies inversely with distance, point $B$ has the highest potential. Points $A$ and $C$ have the same potential by symmetry.

(b) 2 points

For any indication of correct qualitative reasoning about the potential for this particular geometry — 1 point
Example: All points on the arc are a distance $R$ from point $P$. Since potential is a scalar quantity, the potential will be the same as that of a point charge with charge $Q$ located a distance $R$ away.
For a correct answer — 1 point
$V = kQ/R$

*Alternate solution* — *Alternate points*
*For indicating the potential is obtained by integrating the contributions from each part of the charge distribution* — *1 point*

$$V = \int \frac{kdq}{r} \quad \text{where} \quad dq = \lambda r\, d\theta = \frac{Q}{r(\pi/2)} r\, d\theta = \frac{2Q}{\pi} d\theta$$

*Noting that* $r = R$ *for the entire distribution, the integral becomes:*

$$V = \frac{2kQ}{\pi R}\int_0^{\pi/2} d\theta$$

*For a correct answer* — *1 point*
$V = kQ/R$

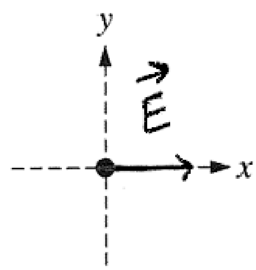
(c) 4 points

For an indication that mechanical energy is conserved — 1 point
$U_i + K_i = U_f + K_f$
For correct substitution of potential energies — 1 point
$U_f = 0$
$U_i = qV$
For substituting the potential at $P$ from part (b) — 1 point
$q(kQ/R) = K_f$
For substituting correctly for the kinetic energy and solving for the velocity — 1 point
$q(kQ/R) = (1/2)mv^2$
$v = \sqrt{2kqQ/mR}$

**Question 1 (continued)**

**Distribution of points**

(d) 1 point




For a vector drawn in the correct direction — horizontally to the right — 1 point

(e) 5 points

For any indication that the net electric field is the integral of all of the horizontal components from each part of the charge — 1 point

$$|\mathbf{E}| = E_x = \int dE_x$$

For correctly using cosine in computing the $x$-component — 1 point

$$|\mathbf{E}| = \int dE\cos\theta = \int \frac{k\,dQ}{R^2}\cos\theta$$

For changing variables to integrate with respect to $\theta$ — 1 point

$$dq = \frac{2Q}{\pi}d\theta$$

For correct limits of integration — 1 point

$$|\mathbf{E}| = \int_{-\pi/4}^{\pi/4} \frac{2kQ}{\pi R^2}\cos\theta\,d\theta$$ (or equivalent limits such as $\frac{3\pi}{4}$ and $\frac{5\pi}{4}$)

$$|E| = \frac{2kQ}{\pi R^2}\sin\theta\Big|_{-\pi/4}^{\pi/4}$$

For a correct answer — 1 point

$$|\mathbf{E}| = \frac{2\sqrt{2}\,kQ}{\pi R^2}$$

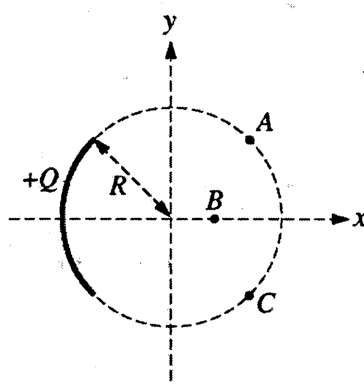
# PHYSICS C: ELECTRICITY AND MAGNETISM

## SECTION II

**Time—45 minutes**

**3 Questions**

**Directions:** Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part, NOT in the green insert.




$\frac{kQ}{r}$

Figure I

E&M. 1.

A charge $+Q$ is uniformly distributed over a quarter circle of radius $R$, as shown above. Points $A$, $B$, and $C$ are located as shown, with $A$ and $C$ located symmetrically relative to the $x$-axis. Express all algebraic answers in terms of the given quantities and fundamental constants.

(a) Rank the magnitude of the electric potential at points $A$, $B$, and $C$ from greatest to least, with number 1 being greatest. If two points have the same potential, give them the same ranking.

__2__ $V_A$ __1__ $V_B$ __2__ $V_C$

Justify your rankings. The quarter circle is symmetric relative to the x-axis, as are A and C. Thus, $V_A = V_C$. B is closer to the charged arc than either A or C, and since potential is inversely related with distance, $V_B > V_A = V_C$.

Point $P$ is at the origin, as shown below, and is the center of curvature of the charge distribution.

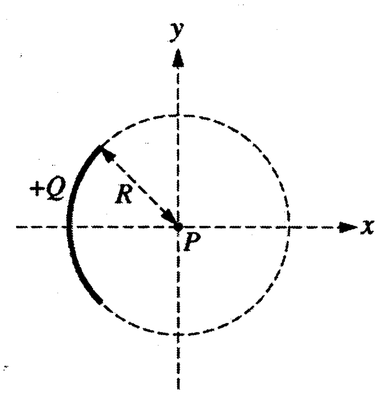



Figure II

(b) Determine an expression for the electric potential at point $P$ due to the charge $Q$.

$dV = \frac{k\,dq}{R}$, Let $\lambda = \frac{Q}{L} = \frac{Q}{\frac{1}{4}(2\pi R)} = \frac{2Q}{\pi R}$, which is linear charge density.

Then $dq = \lambda\, d\ell$, So $dV = \frac{k\lambda\, d\ell}{R}$

$$V = \int dV = \int_0^{\frac{\pi}{2}R} \frac{k\lambda\, d\ell}{R} = \frac{k\lambda \cdot \frac{\pi}{2}R}{R} = \frac{k\lambda\pi}{2} = \frac{k\frac{2Q}{\pi R}\pi}{2} = \boxed{\frac{kQ}{R}}$$

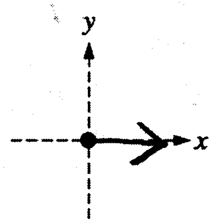
(c) A positive point charge $q$ with mass $m$ is placed at point $P$ and released from rest. Derive an expression for the speed of the point charge when it is very far from the origin.

initial energy $= V_0 \cdot q = \frac{kQq}{R}$, because the charge has electric potential energy

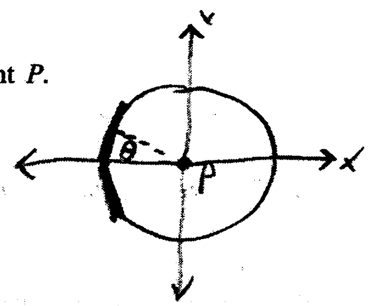
final energy $= \frac{1}{2}mv^2$, because the charge has kinetic energy

final = initial $\Rightarrow \frac{kQq}{R} = \frac{1}{2}mv^2 \Rightarrow \boxed{v = \sqrt{\frac{2kQq}{mR}}}$

(d) On the dot representing point $P$ below, indicate the direction of the electric field at point $P$ due to the charge $Q$.




(e) Derive an expression for the magnitude of the electric field at point $P$.




$$dE = \frac{k\,dq}{R^2} = \frac{k\lambda\, d\ell}{R^2} = \frac{k\lambda R\, d\theta}{R^2} = \frac{k\lambda\, d\theta}{R}$$

$$dE_x = \frac{k\lambda\cos\theta}{R}\, d\theta$$

$$E_x = \frac{k\lambda}{R}\int_{-\pi/4}^{\pi/4} \cos\theta\, d\theta = \frac{k\lambda}{R}\Big[\sin\theta\Big]_{-\frac{\pi}{4}}^{\pi/4} = \frac{2k\lambda}{R}\cdot \sin\frac{\pi}{4} = \frac{2k\lambda}{R}\cdot\frac{\sqrt{2}}{2} = \frac{\sqrt{2}k\lambda}{R}$$

$$= \frac{\sqrt{2}k}{R}\,\frac{2Q}{\pi R} = \boxed{\frac{2\sqrt{2}kQ}{\pi R^2}}$$

# PHYSICS C: ELECTRICITY AND MAGNETISM

## SECTION II
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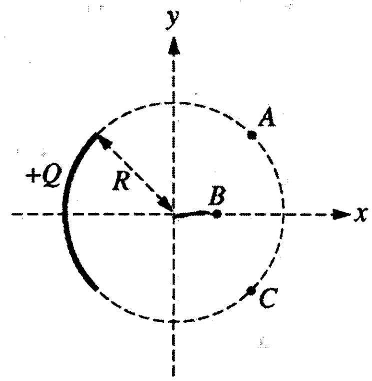


Figure I

E&M. 1.

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(a) Rank the magnitude of the electric potential at points $A$, $B$, and $C$ from greatest to least, with number 1 being greatest. If two points have the same potential, give them the same ranking.

2 $V_A$ 1 $V_B$ 2 $V_C$

Justify your rankings.

$V = \frac{kQ}{r}$, B is the closest so the V will be the greatest
A & C are the same distance apart from the +Q charge

Point $P$ is at the origin, as shown below, and is the center of curvature of the charge distribution.

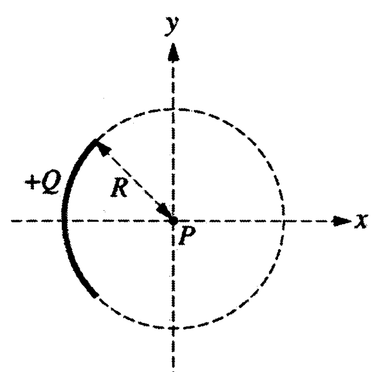



Figure II

(b) Determine an expression for the electric potential at point $P$ due to the charge $Q$.

$$V = \frac{kq}{r} = \frac{kQ}{R}$$

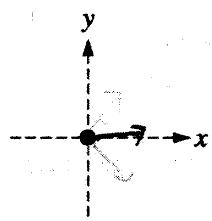
(c) A positive point charge $q$ with mass $m$ is placed at point $P$ and released from rest. Derive an expression for the speed of the point charge when it is very far from the origin.

$$KE = qV$$

$$\frac{1}{2}mv^2 = q\frac{KQq}{R}$$

$$v = \sqrt{\frac{2KQq^2}{m}}$$

(d) On the dot representing point $P$ below, indicate the direction of the electric field at point $P$ due to the charge $Q$.




(e) Derive an expression for the magnitude of the electric field at point $P$.

$$F = Eq$$

$$= \frac{kQq^2}{R}$$

$$E = \frac{kQq}{R^2}$$

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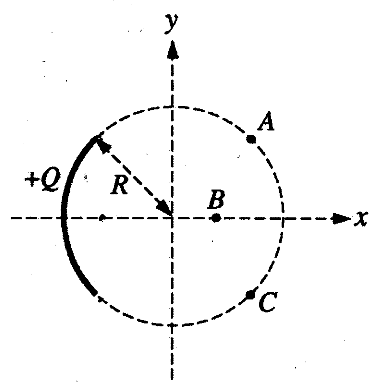


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(a) Rank the magnitude of the electric potential at points $A$, $B$, and $C$ from greatest to least, with number 1 being greatest. If two points have the same potential, give them the same ranking.

2 $V_A$ 1 $V_B$ 2 $V_C$

Justify your rankings.

$V = \frac{1}{4\pi\varepsilon_0} \sum \frac{q_i}{r_i}$

B is the closest point to the most part of the charged section therefore A will have the greatest potential while A and C being same distance from the line will have a lower potential.

Point $P$ is at the origin, as shown below, and is the center of curvature of the charge distribution.

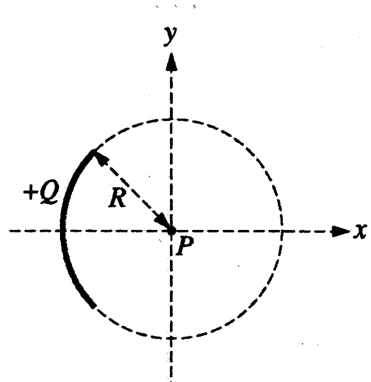



Figure II

(b) Determine an expression for the electric potential at point $P$ due to the charge $Q$.

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q_i}{r}$$

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R}$$

(c) A positive point charge $q$ with mass $m$ is placed at point $P$ and released from rest. Derive an expression for the speed of the point charge when it is very far from the origin.

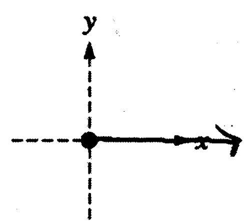
q m P

$$E = \frac{F}{q}$$

$$F = \frac{1}{4\pi\varepsilon_0}\int_0^\infty \frac{q(Q)}{r}$$

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

(d) On the dot representing point $P$ below, indicate the direction of the electric field at point $P$ due to the charge $Q$.




(e) Derive an expression for the magnitude of the electric field at point $P$.

$$E = \frac{-dV}{dr}$$

$$E = \int \frac{Q}{\varepsilon_0}$$

$$E = \frac{\frac{1}{4\pi\varepsilon_0}\frac{Q}{R}}{dr}$$

## Question 1

### Overview

This question assessed students' understanding of electrostatics. In part (a) students were asked to reason qualitatively about the value of the electric potential near a quarter-circle of charge. In part (b) students were asked to derive an expression for the electric potential at the center of curvature of that quarter-circle of charge. In part (c) a charge was released from rest at the center of curvature, and students were asked to calculate the speed of the charge when it was a large distance away from the charge distribution. In parts (d) and (e) students were asked for the direction and magnitude of the electric field at the center of curvature of the charge distribution.

**Sample: E1-A**
**Score: 15**

This response earned full credit. In part (a) the response appropriately states that the "potential is inversely related" to distance, as opposed to inversely proportional which is technically not true since this is not a point charge distribution. The derivations in the other parts are very detailed, with each step easy to read and final answers enclosed in a box. Note that part (b) correctly performs an integration over $d\ell$ instead of $d\theta$, as illustrated in the alternate solution.

**Sample: E1-B**
**Score: 9**

Parts (a) and (b) earned full credit. The response in part (c) is mostly correct but has an extra $q$ in the expression for the potential and thus lost that substitution point. Part (d) earned full credit, but part (e) earned no points.

**Sample: E1-C**
**Score: 6**

Parts (a) and (b) earned full credit. Part (b) nicely shows the general principle first and then the specific application to this question. Parts (c) and (e) earned no credit, but the correct arrow was drawn in part (d), earning 1 point.